Time Of Flight

PHENIX Focus Time Of Flight

H. Masui

For the TOF group

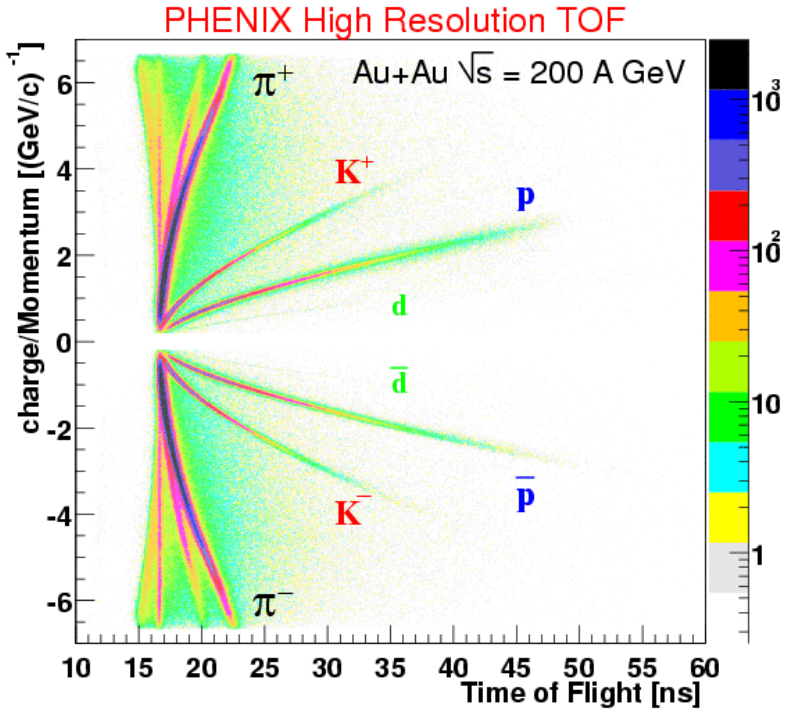
Outline

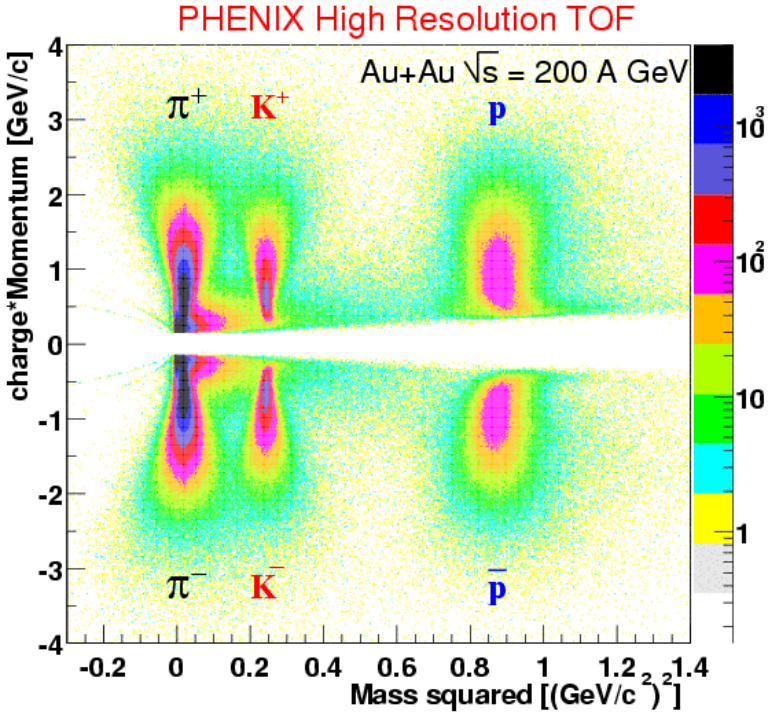
- Purpose of PHENIX TOF
- Basics
- Hardware Design & Readout
- Timing Measurement
- Calibration
- Physics Results
- Summary

Purpose of PHENIX TOF

- Hadron measurement / Particle Identification (PID)
  - Charged hadrons (π/K/p/d)
  - From low p_T to high p_T.
    - Intrinsic timing resolution Δt ~ 80 – 100 ps (design value).
    - PID capability, assume 4 sigma separation at the flight path of 5m.
      - π/K separation up to p_T ~ 2.4 GeV/c
      - K/p separation up to p_T ~ 4 GeV/c

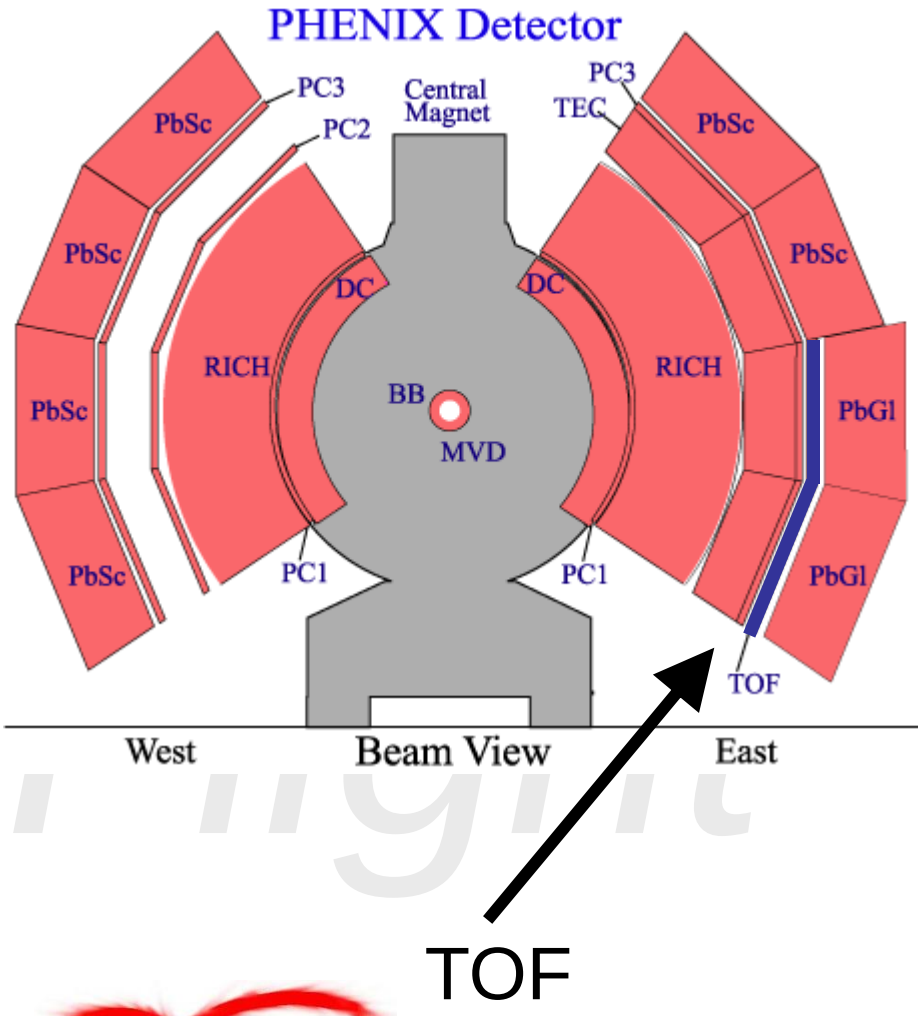
Basics





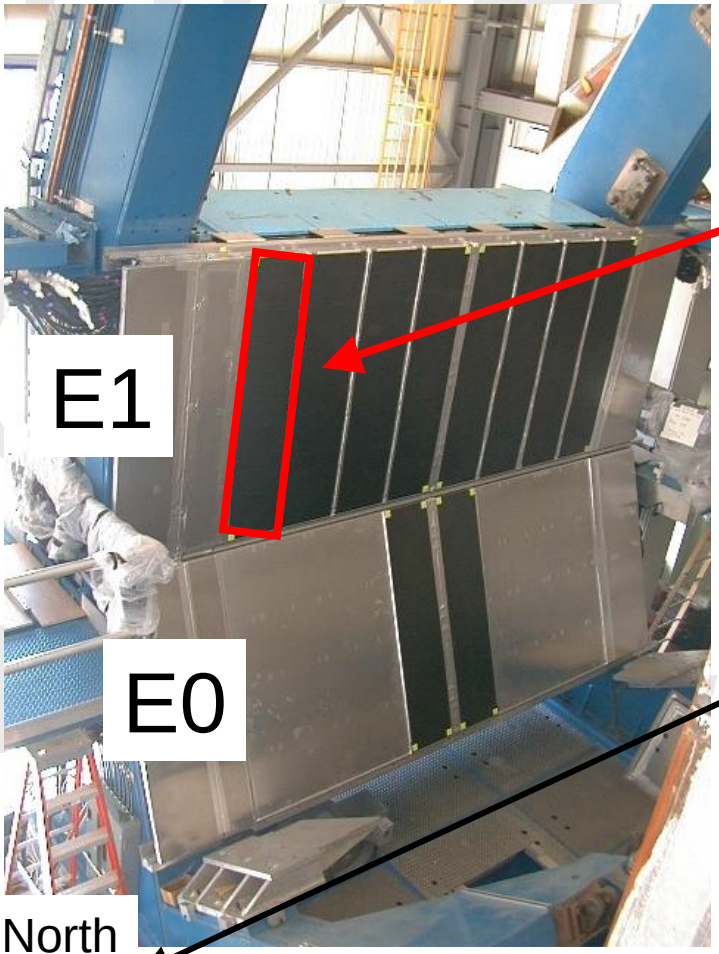
$$t = \frac{L}{c\beta} = \frac{L}{c}\frac{\sqrt{p^2 + m^2}}{p} \longrightarrow m^2 = p^2\left\{\left(\frac{t^2}{L^2}\right) - 1\right\}$$

Where is it ?



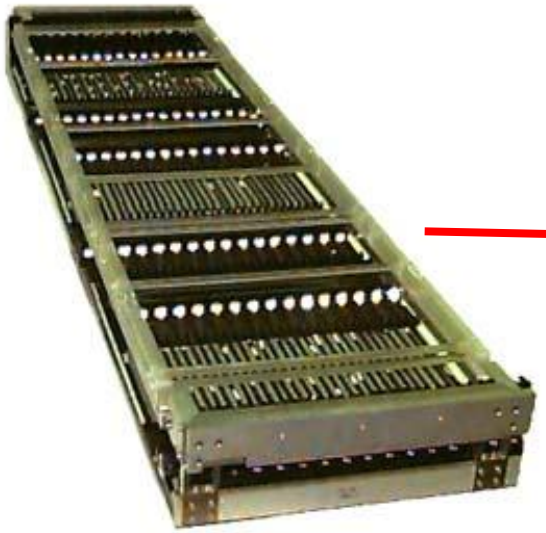
- East Arm
  - Sector 0 & 1
  - 5 meter from vertex.
- Acceptance
  - $\Delta\phi = \pi/4$
  - $|\eta| < 0.35$
- Segmentation
  - Keep the occupancy < 10 %
    - Lose timing information by double hit.
  - $dN_{ch}/dy \sim 1500$
    → 1000 segments.
    → ~ 100 cm^2/segment at 5 m from vertex.

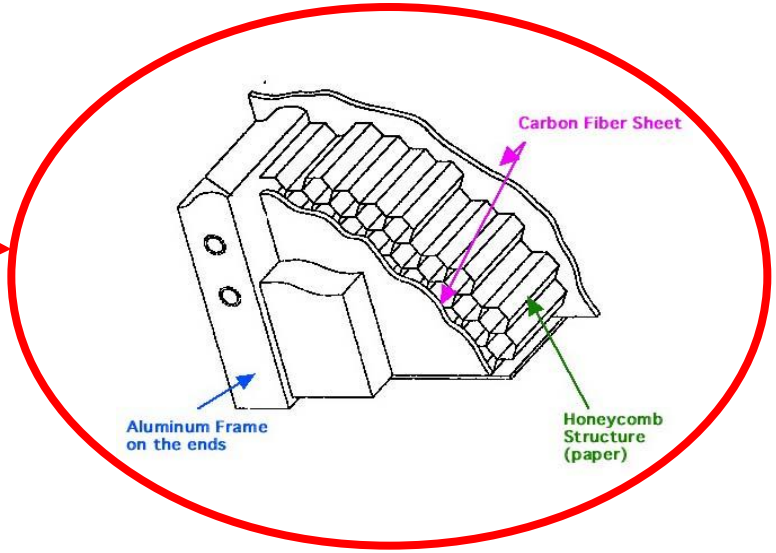
Hardware design
(i) Panel



- "Panel"
  - TOF consists of 10 panels.
  - 8 panels are located on sector 1 and 2 panels on sector 0.

Detail view of TOF panel



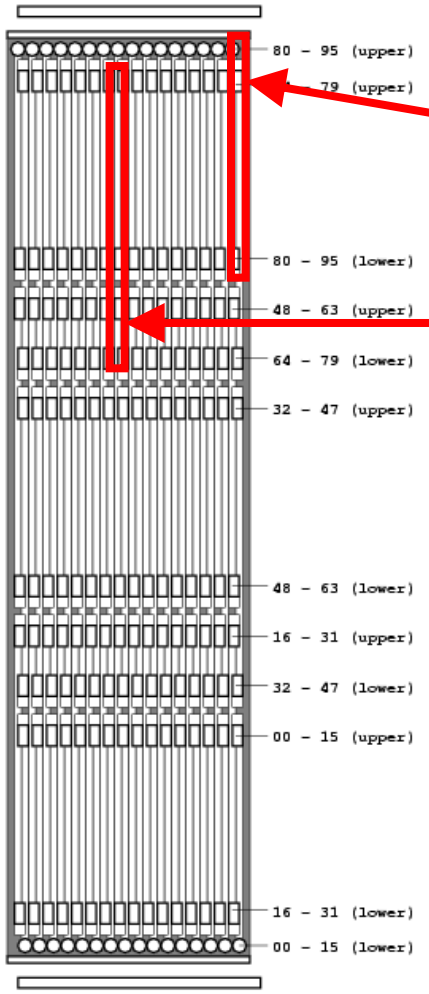


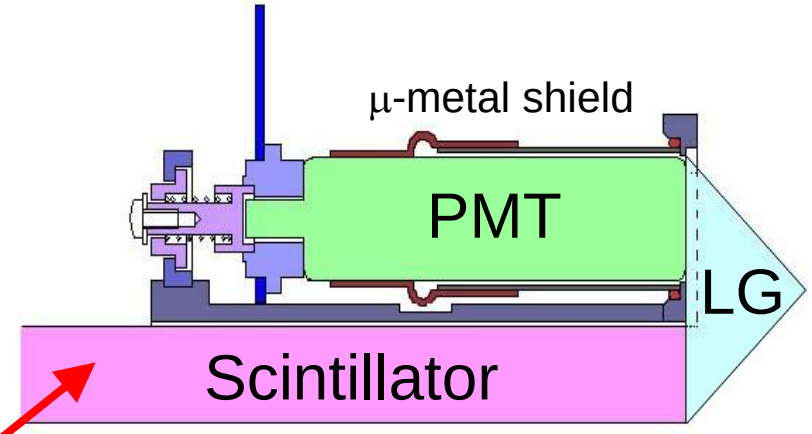
Material		Components (L_{RAD} [cm])	L (mm)	L_{RAD} (%)
PMT(side,Dy,Insu.)		SiO_2(12.7)+Fe(1.6)+Al_2O_3(8.9)	1.6+0.4+0.05	3.8
μ-metal		Fe(1.76)	1.0	5.68
PMT support		Lucite(34.4)	8	2.32
Scintillator		Plastic(42.4)	15.1	3.56
(Light guide)		Lucite(34.4)	(23.3)	(6.77)
Honey Comb		Carbon(18.8)	6.35	3.37
TOTAL				18.7

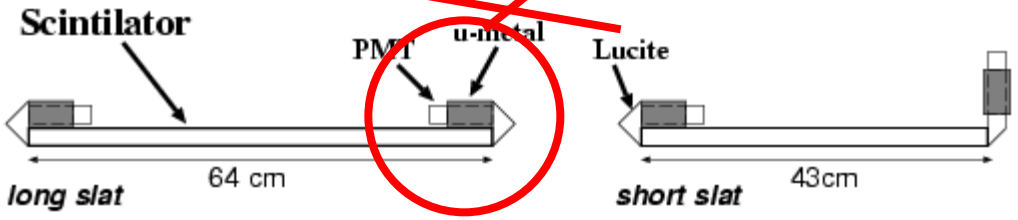
- TOF Panel
  - 15.7 * 192 * 49 cm^3
  - Mechanical structure
    - Honeycomb + carbon fiber sheet for supporting structure with “no mass”.

Hardware design

Panel (ii) Slat



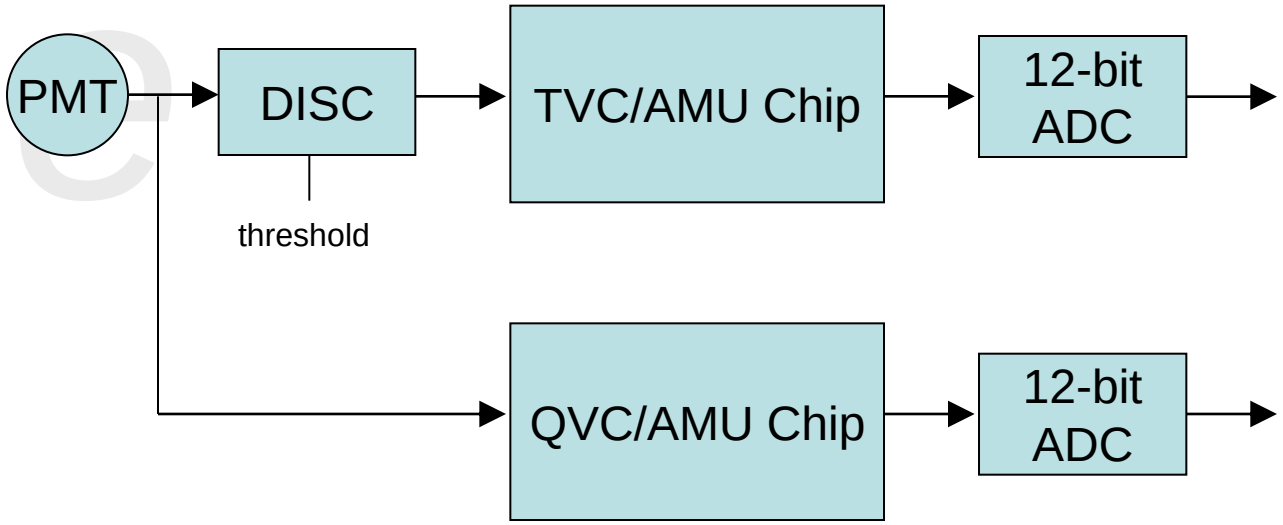




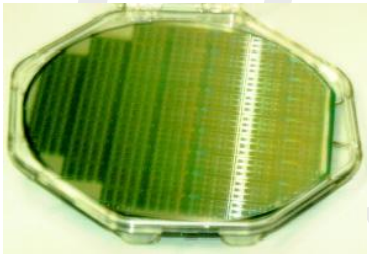
- "Slat" (plastic scintillator)
  - BICRON BC-404
  - 2 types of slats. Long & short
  - Each panel have 96 slats (long:64, short:32).
    - Each slat have 2 read out PMT's.
    - PMT : Hamamatsu R3478S.
  - Total 960 slats with 1920 read out PMT's.
  - Easy maintenance of PMT and bleeder.
  - Easy light shield using rubber tube & O-ring.

Readout : TOF–FEM

Front-End Module

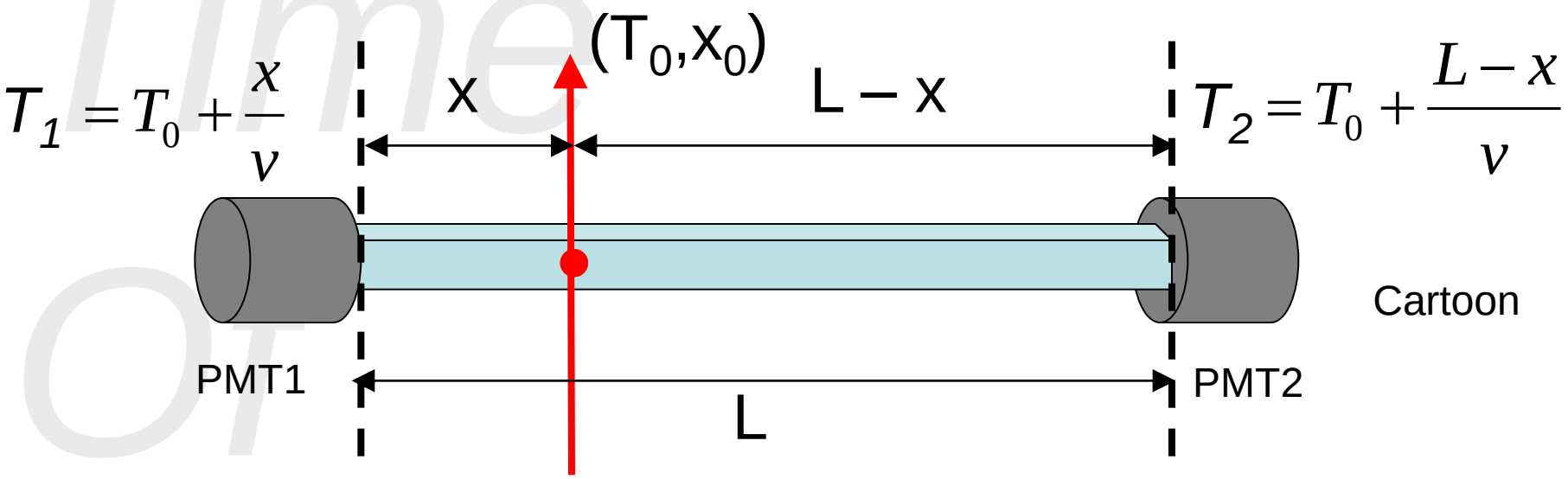


TVC-AMU chip on the silicon water



- Custom-made chips of TVC+AMU and QVC+AMU.
- From the bench test results of TOF FEE @ Nevis Lab.
  - TVC
    - Overall timing resolution < 25 ps.
    - No dead region in the TVC active range. The dead region < 5 ns.
  - QVC
    - Pedestal width ~ 1.5 ch
- Programmable Analogue Memory Unit
  - Programmable up to 4 μ sec ~ 40 RHIC bunch crossing time.
- Clock is shared with BBC FEM which is transmitted by differential ECL.

Principle of Timing measurement



Cartoon

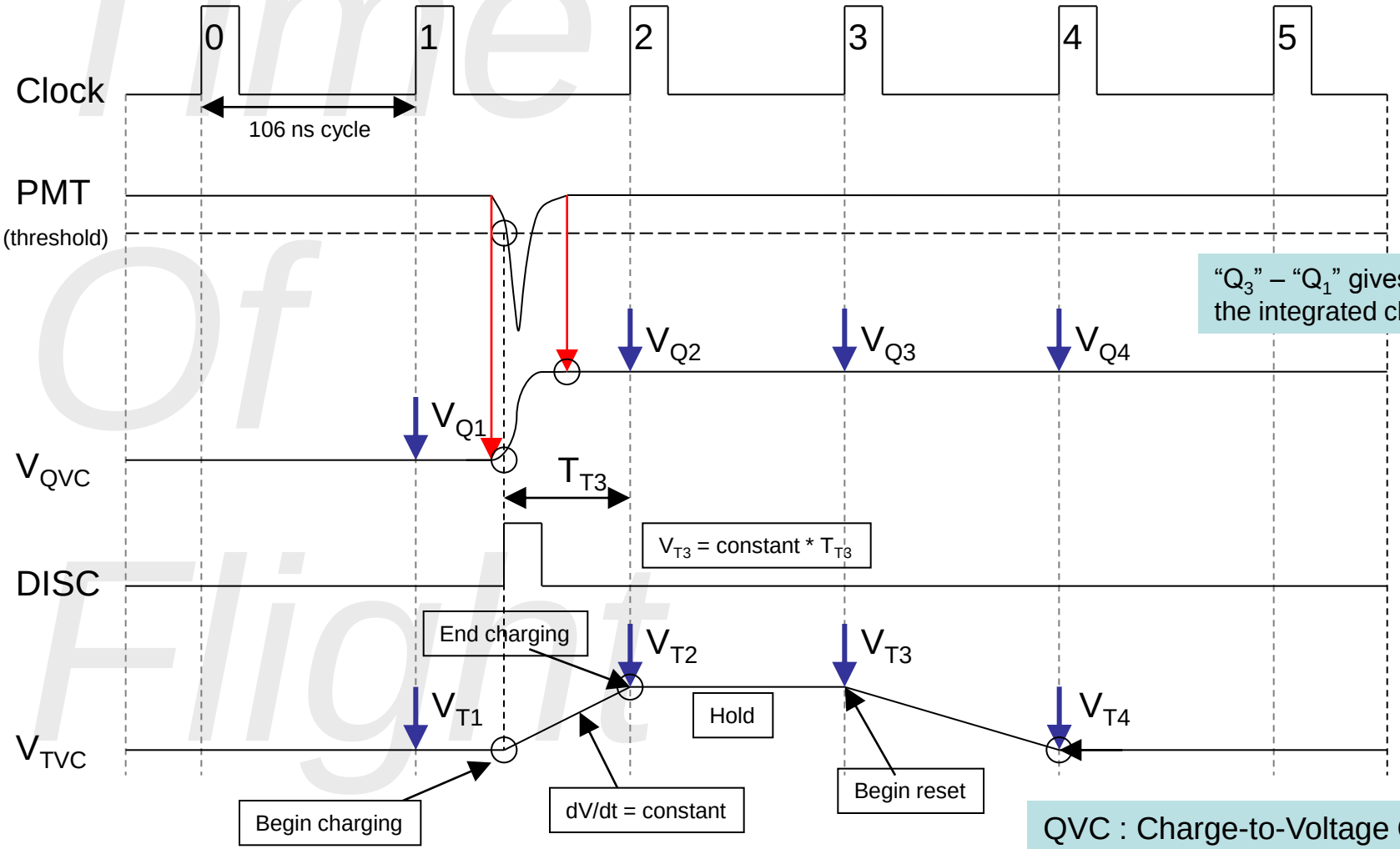
$$TOF = \frac{(T_1 + T_2) - L/v}{2}$$

$$Y\ position = \frac{T_1 - T_2}{2} v$$

T_1, T_2 : Timing measured by PMT1,2
L : slat length
v : light velocity in scintillator

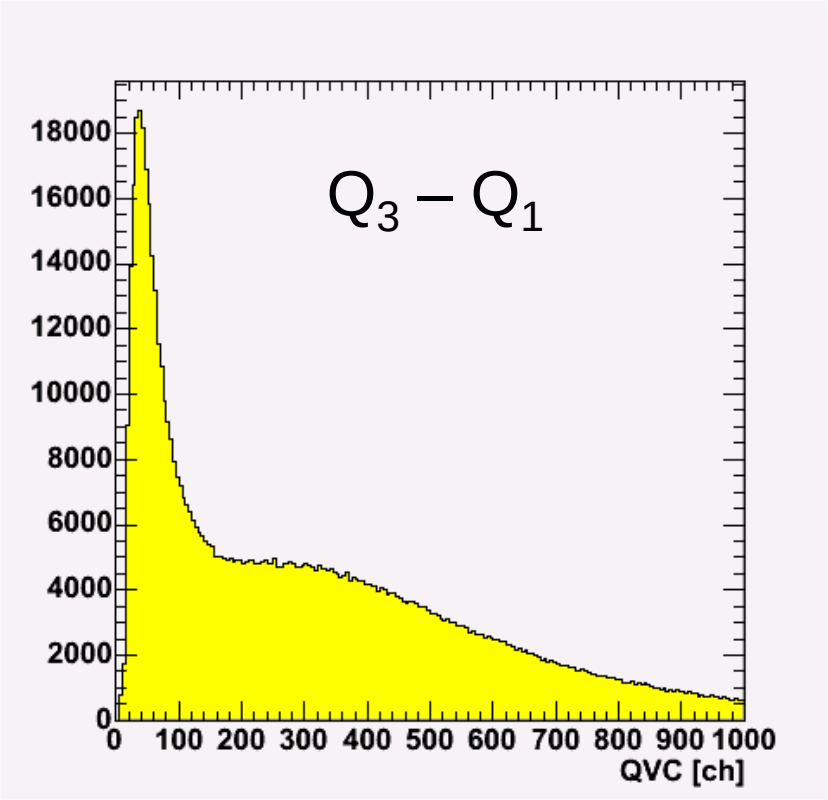
Timing (and charge) measurement as an example

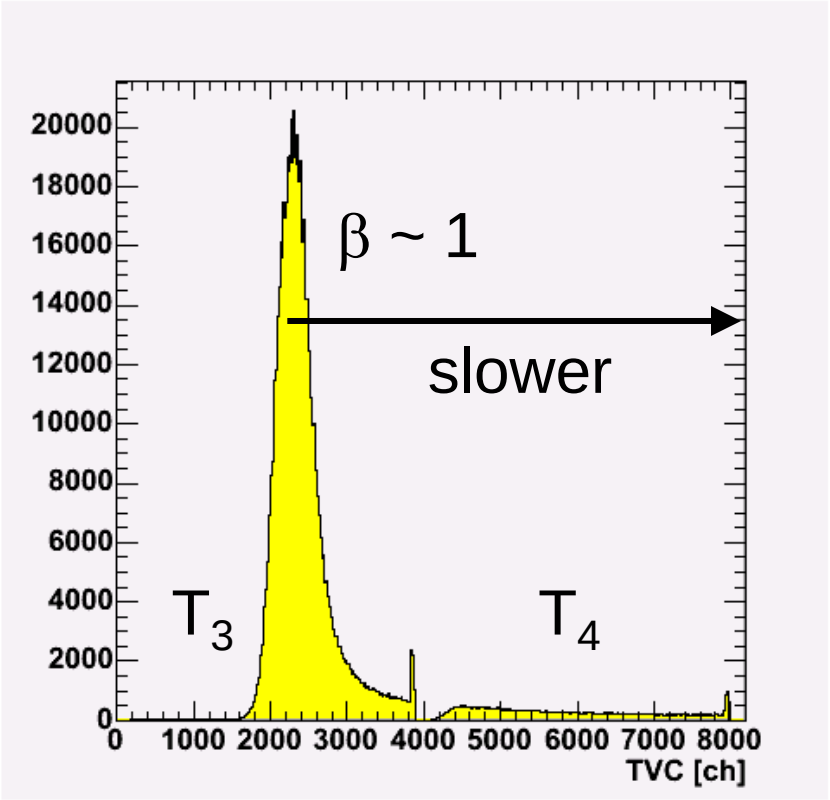
Clock IDs should be arbitrary



QVC : Charge-to-Voltage Converter
TVC : Time-to-Voltage Converter

Raw Charge/Timing distribution



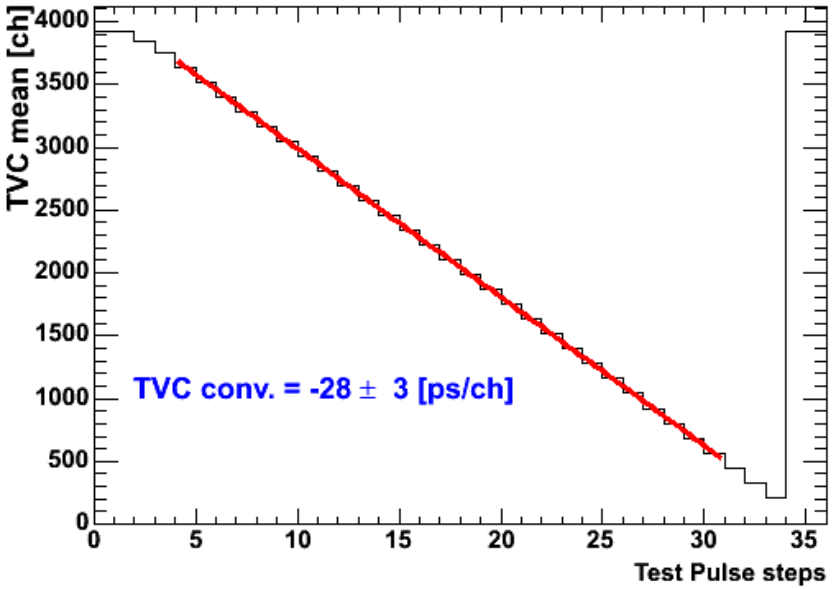


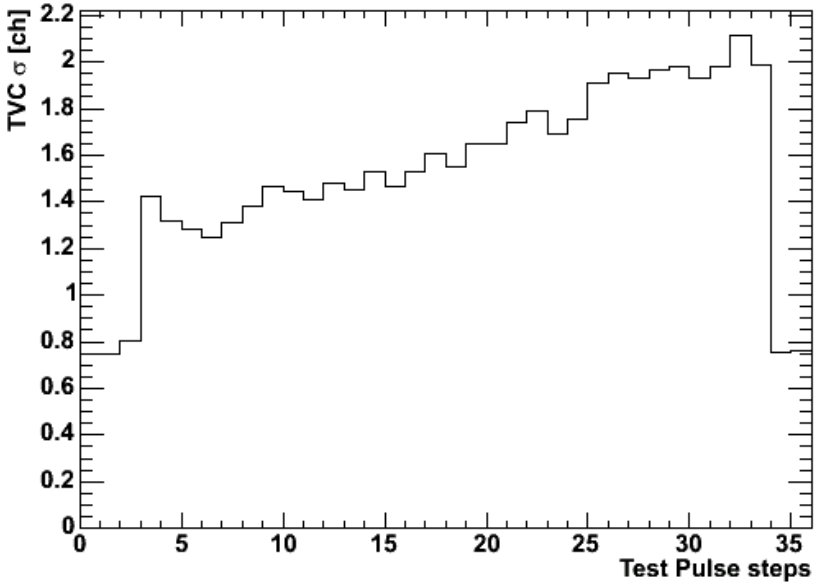
- QVC/TVC distribution
  - Overlay for all channels

Calibration

- TOF calibration
  - 4 steps and 6 parameters.
  - 0th step (online, “TSCAN”)
    - FEM TVC conversion parameter [ps/ch] (PMT by PMT)
  - 1st step (offline)
    - Energy loss conversion parameter [GeV/ch] (slat by slat)
    - Global timing offset [ns] (1)
  - 2nd step
    - Timing offset [ns] (slat by slat)
    - Y position offset [cm] (slat by slat)
    - Light velocity in scintillator [cm/ns] (slat by slat)
  - 3rd step
    - Slewing parameter [ns] (PMT by PMT)
  - 4th step
    - Run by run timing offset [ns]

0th step
FEM TVC calibration “TSCAN”

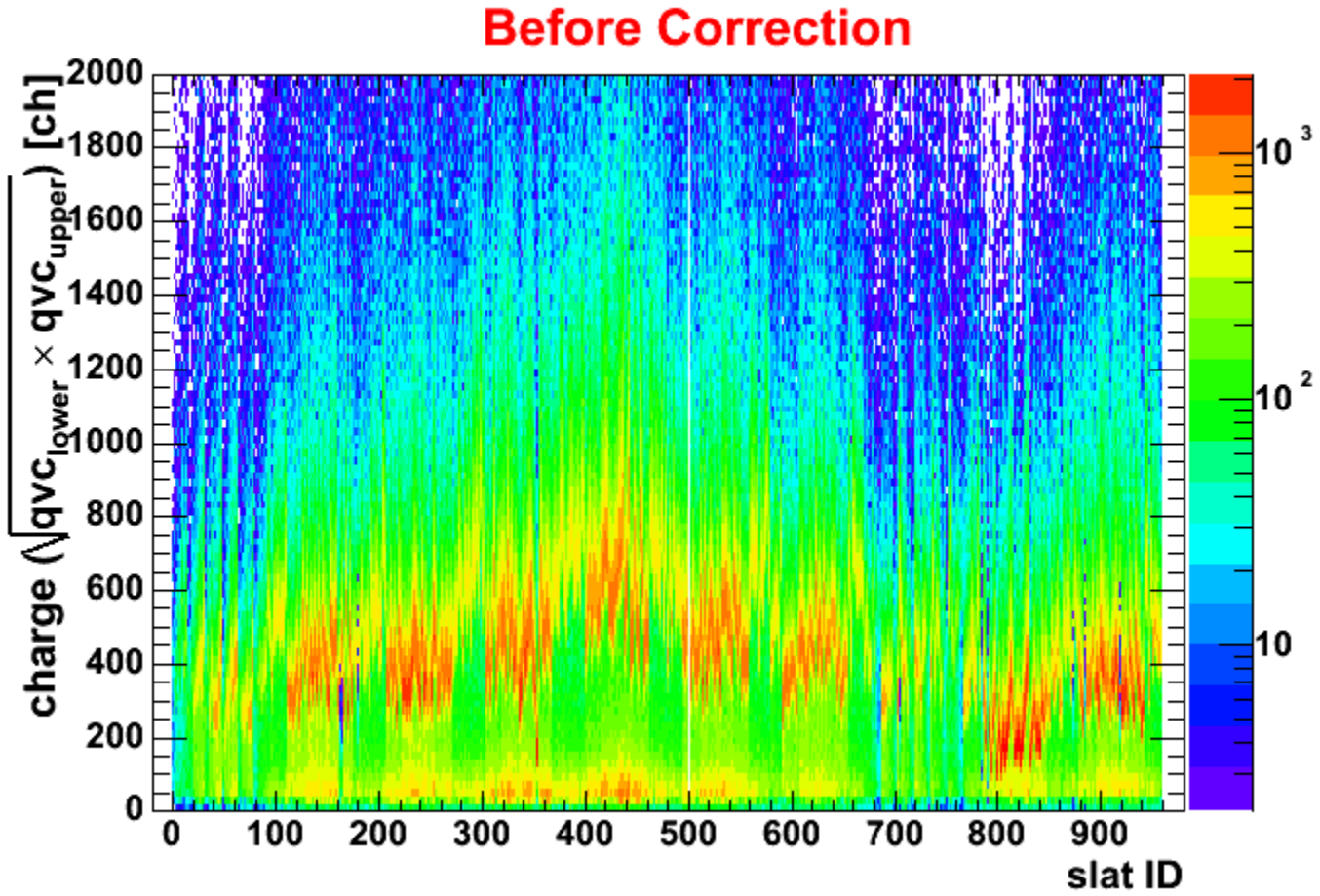




slow ◄——————► fast

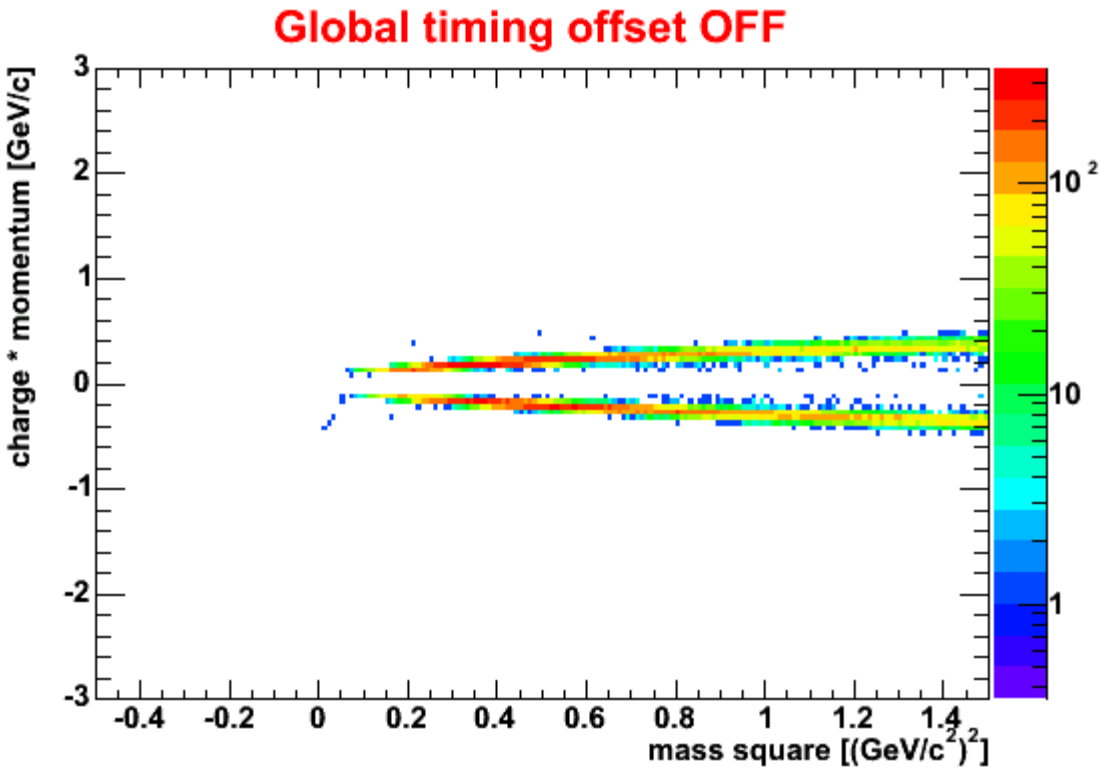
- Everyday calibration data with test pulse (TSCAN)
  - Channel to picosec converter.
  - 1 TP step is ~ 3.3 ns.
  - TVC conversion parameter ~ 28 [ps/ch]

1st step
Energy loss conversion parameter



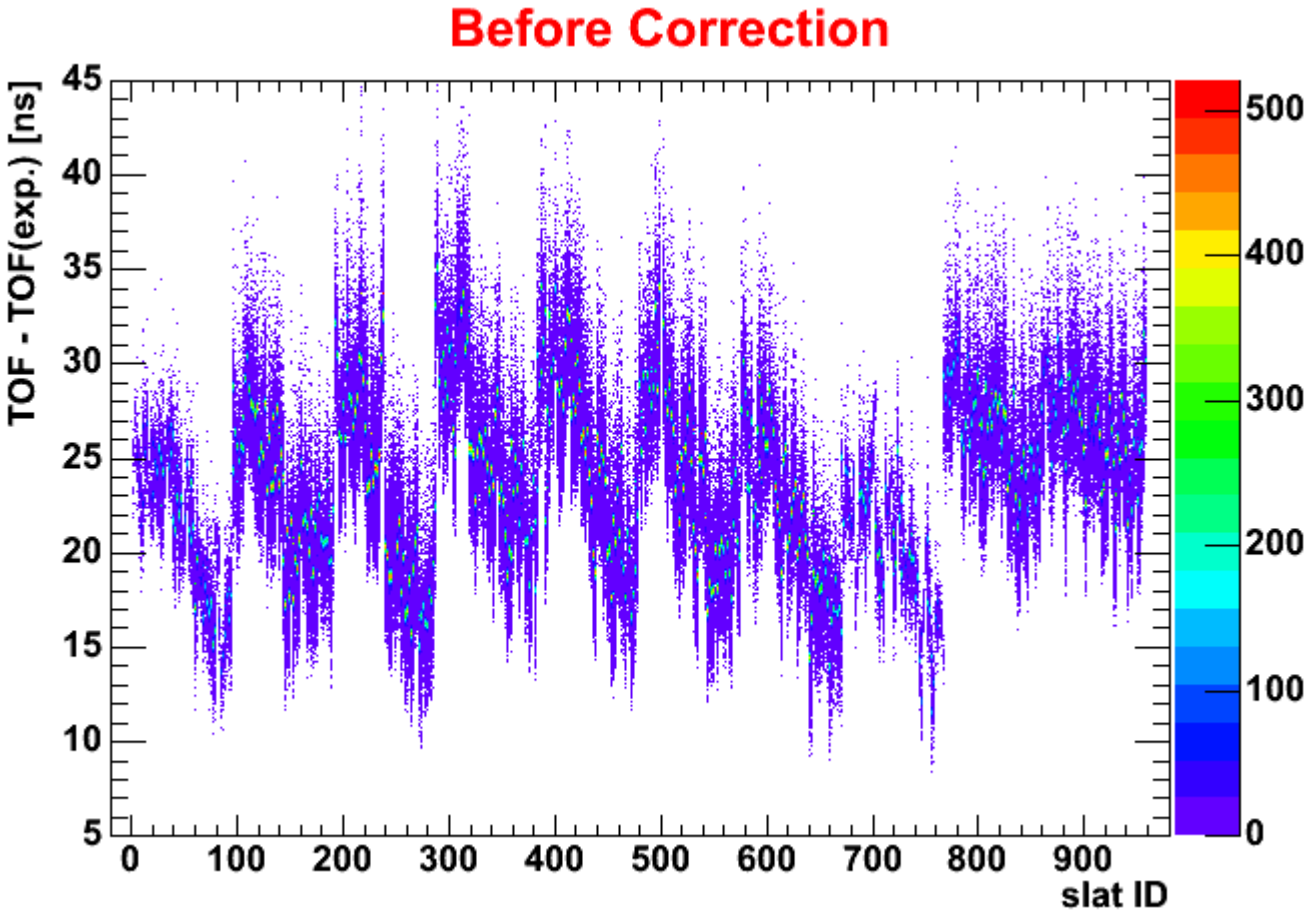
- Channel to GeV converter.
- Fitting by Landau function.
- MIP ~ 3 MeV.

1st step
Global timing offset



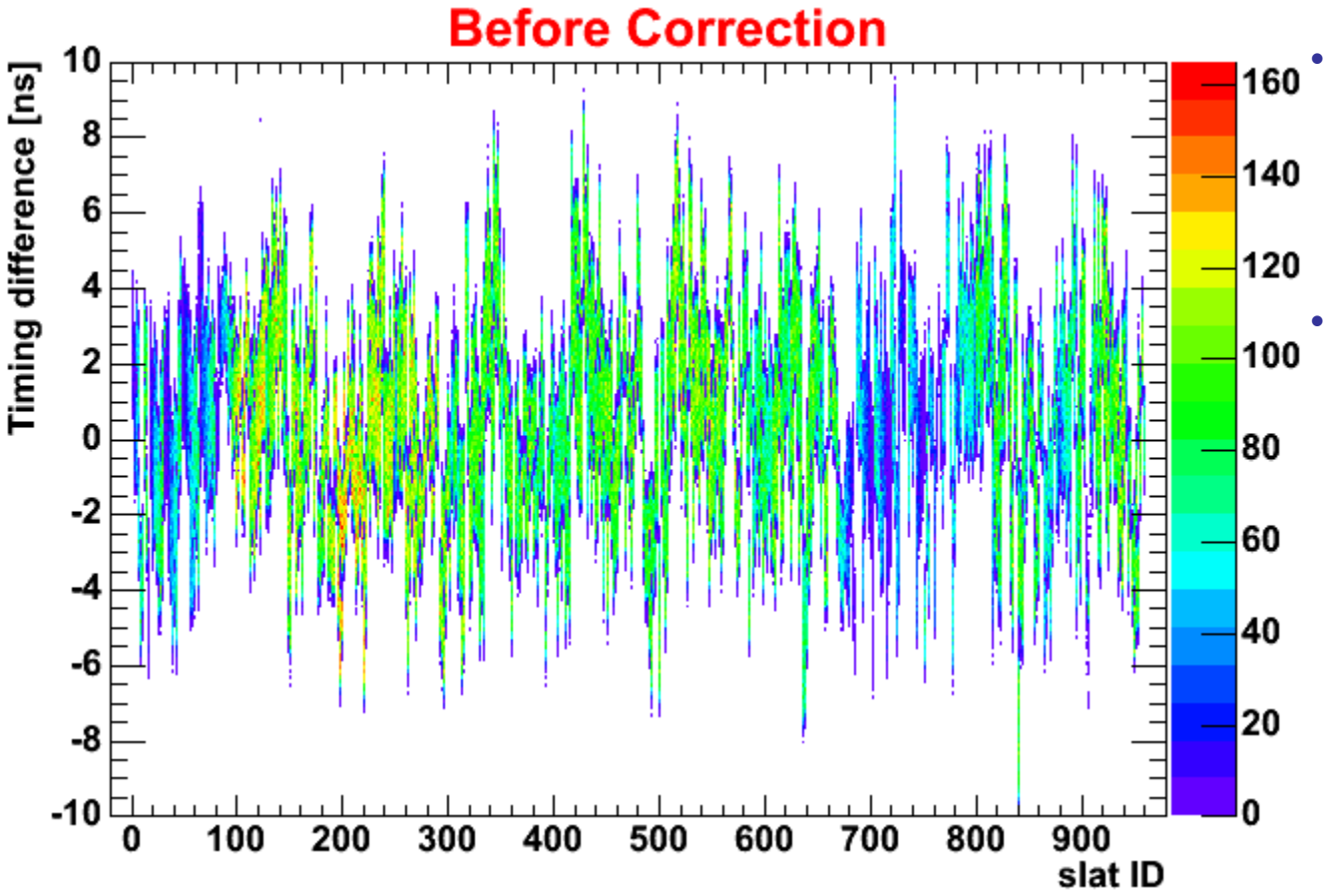
- Global timing offset
  - For adjustment of mass^2 centroid.
  - ~ 20 ns.

Slat by slat Timing offset



- Timing offset is given by difference between measured TOF and pion flight time (TOF(exp.)).
  - Pion flight time
  - ~ 20 ns @ p ~ 0.2 GeV/c
  - ~ 17 ns @ p ~ 2.0 GeV/c

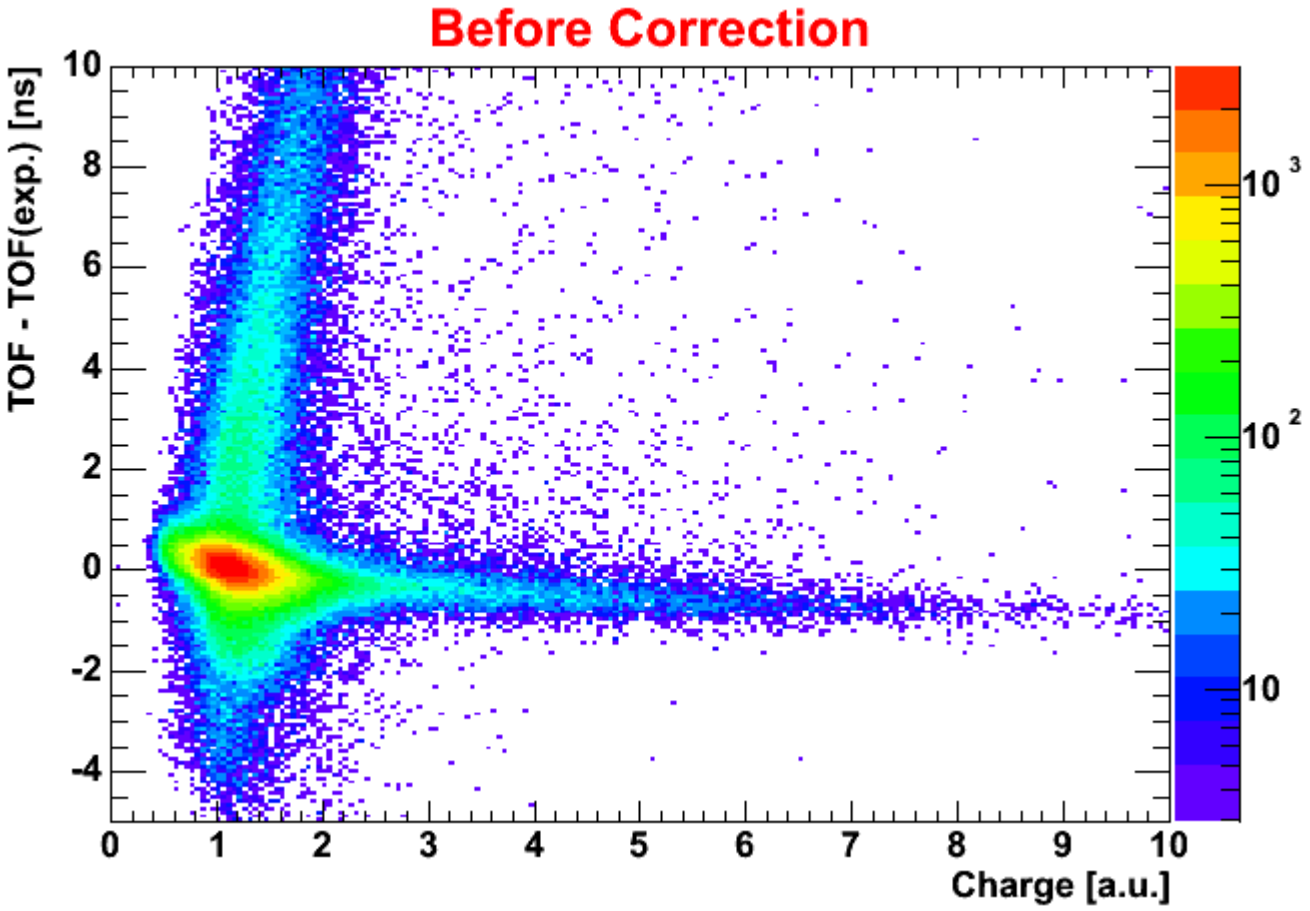
Y position offset & Light velocity in scintillator



- Timing difference between lower and upper PMT.
  - Local y hit position.
- Fitting function

$$Y = \left(\frac{T_0 - T_1}{2} \right) v_{light} - Y_{offset}$$

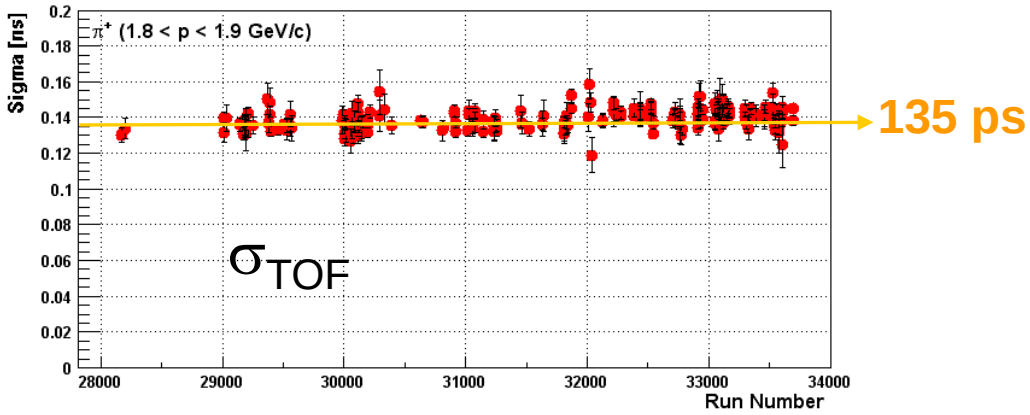
3rd step
Slewing parameter



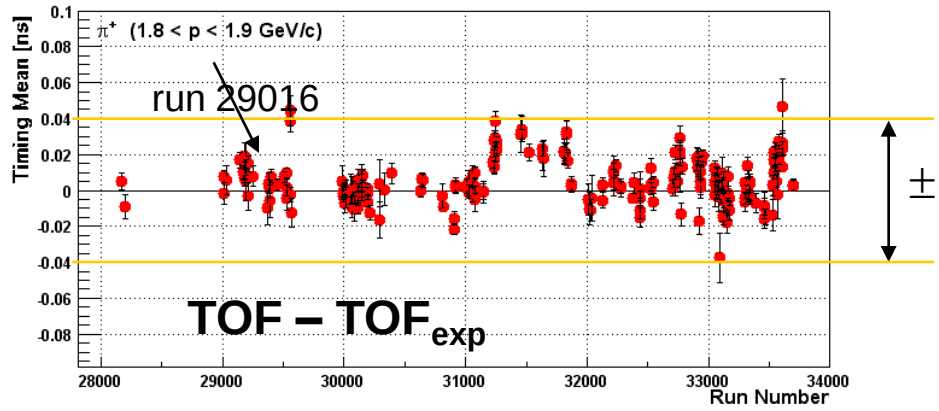
- Slewing correction
  - Fitting function

  F = a + b/sqrt(x)
- Need large statistics if slewing correction is performed PMT by PMT.
  - Additional gain calibration
  - Fitting for sum of all upper and lower PMT.

4th step
Run by run timing offset

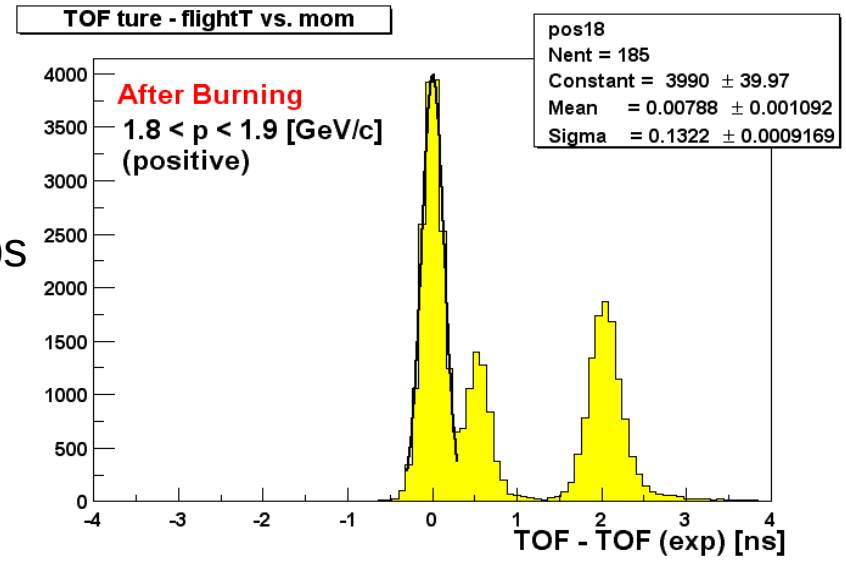


135 ps

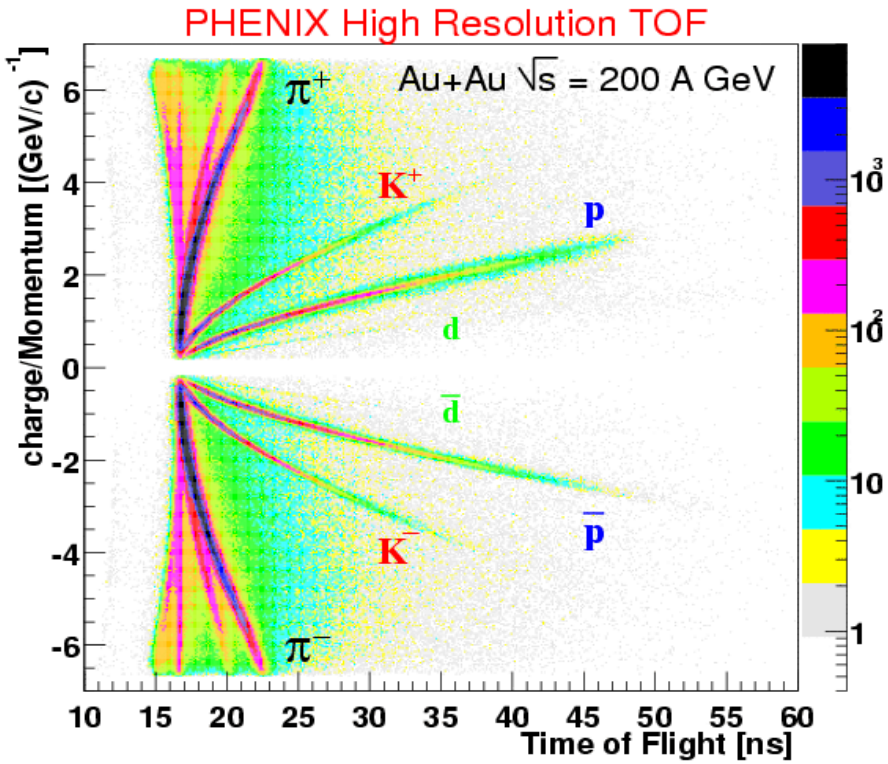


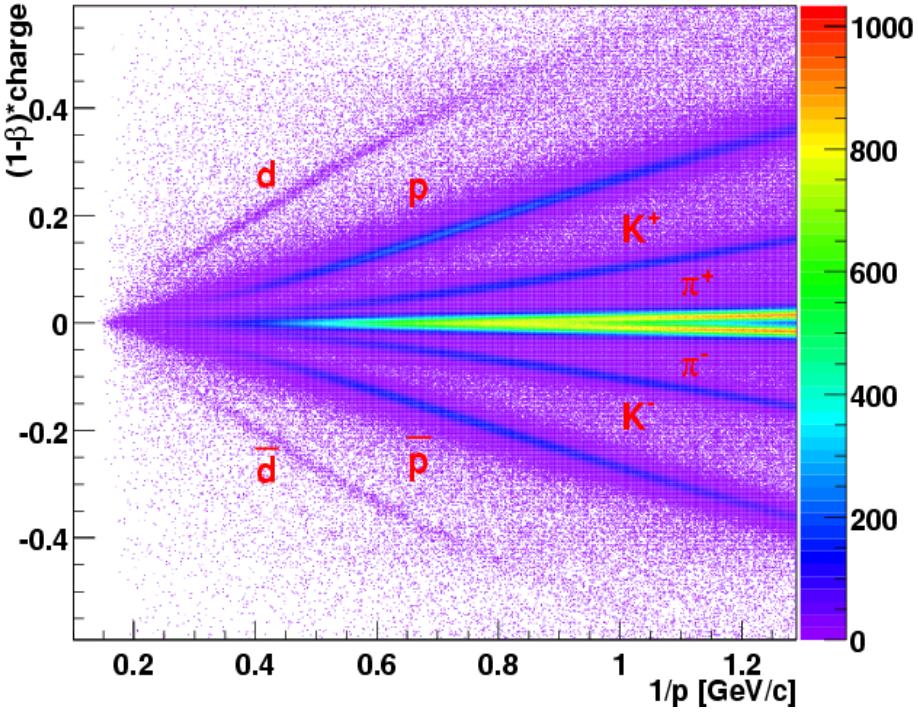
± 40 ps

- Run2 Au + Au :
  - Selected high momentum π^+ (1.8 < p < 1.9 GeV/c)



Hadron identification



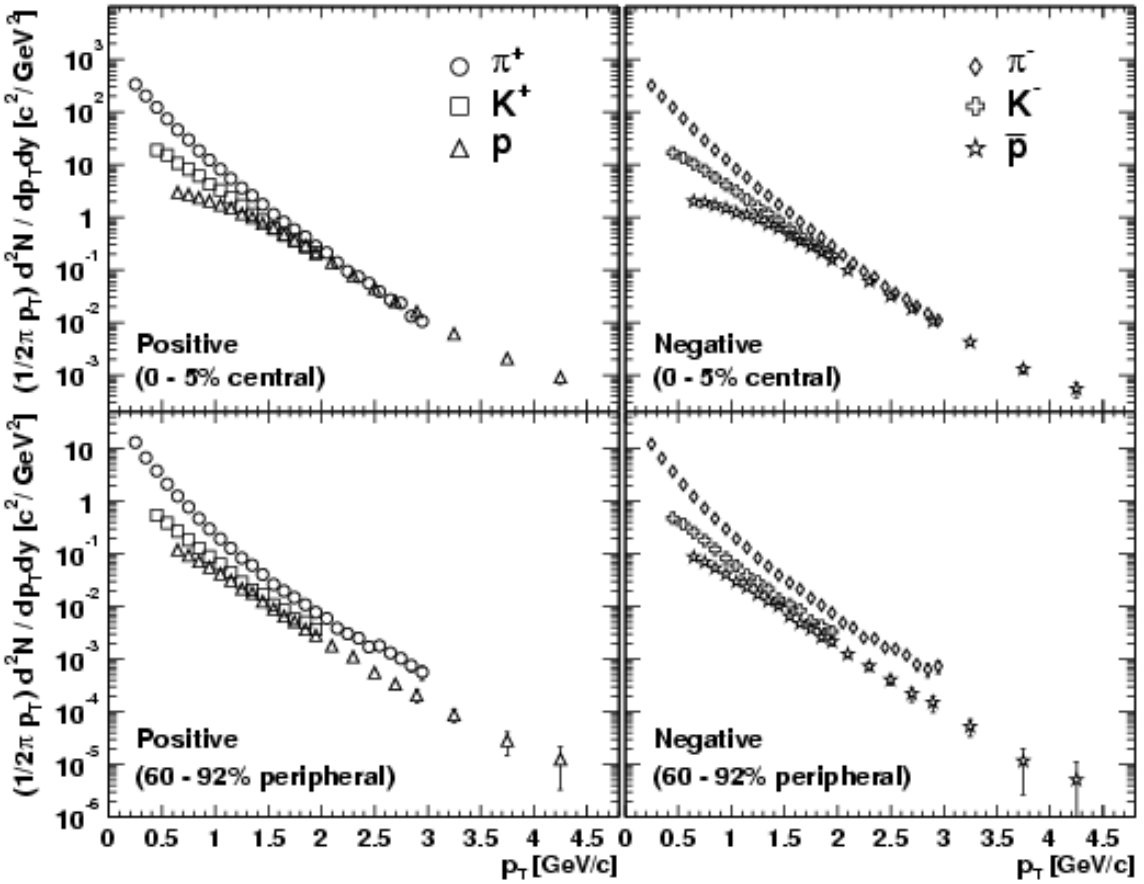


- Pion, Kaon, Proton and deuteron are clearly identified !
  - Overall ~ 120 ps (overall, in mass^2) time resolution is achieved.

Physics Results

PHENIX: PRC accepted, nucl-ex/0307022

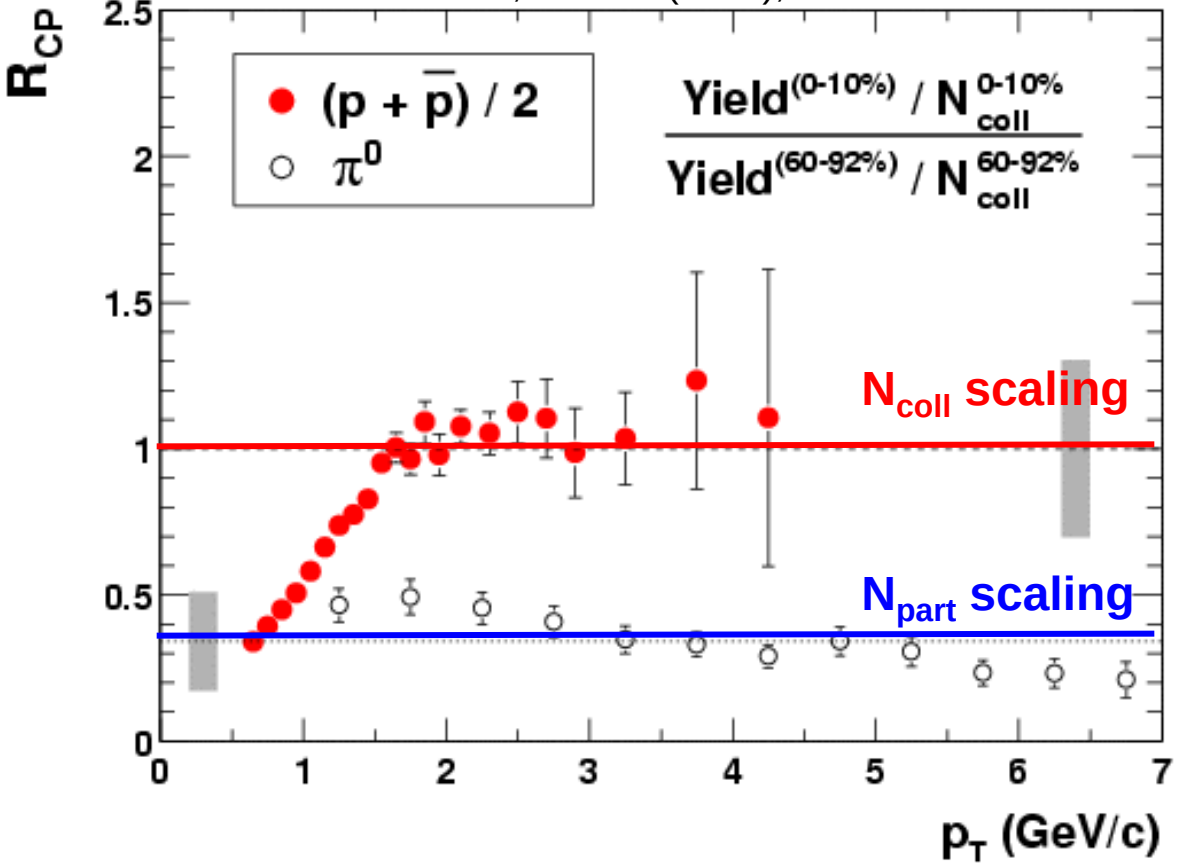
- Single particle p_T spectra
  - Central
    - Low p_T slopes increase with mass.
    - Proton and anti-proton yield ~ pion yiled @ high p_T.
  - Peripheral
    - Mass dependence is less pronounced.
    - Similar to p + p.



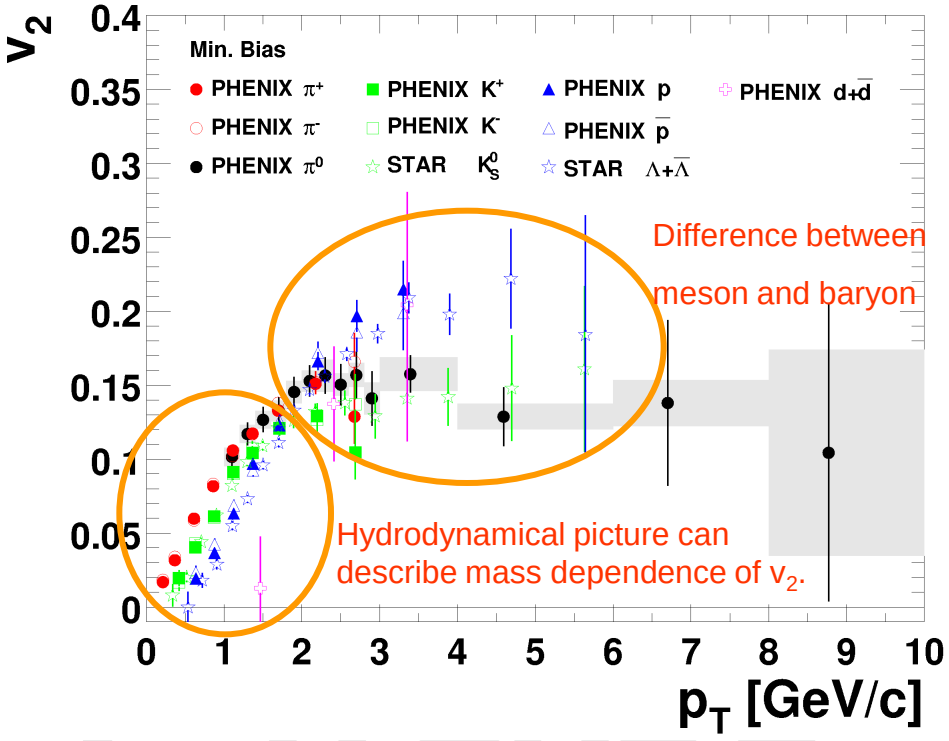
Physics Results

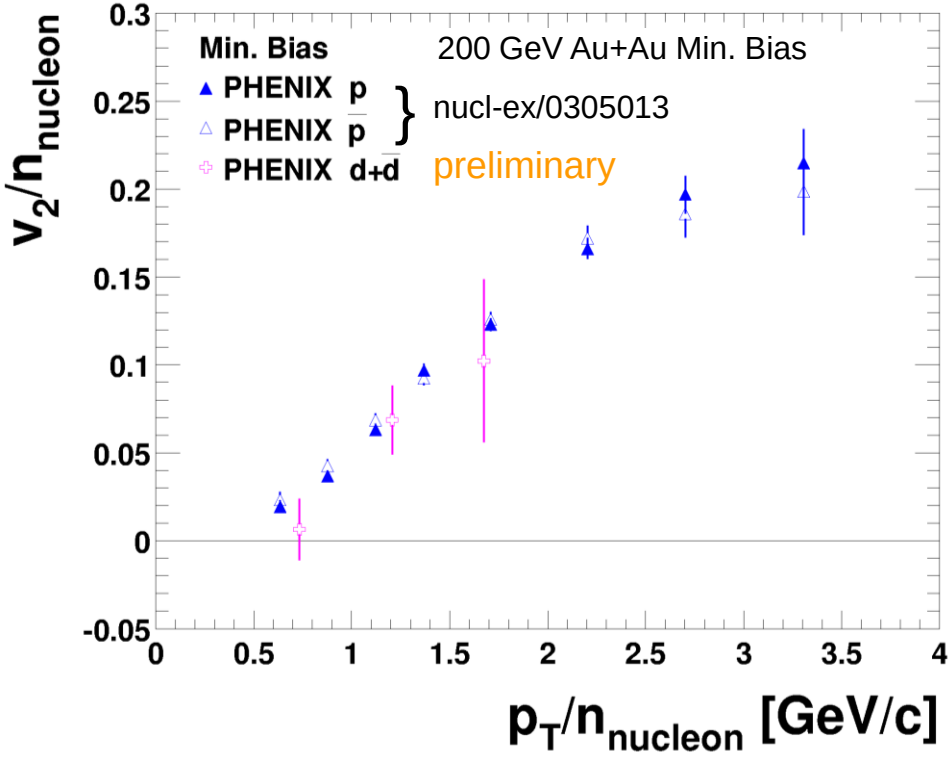
- Central-to-Peripheral ratio (R_{cp}) vs p_T
  - Proton
    - No suppression, Ncoll scaling @ 1.5 – 4.5 GeV/c.
  - π_0
    - Suppression
    - central > peripheral

PHENIX: PRL 91, 172301 (2003), nucl-ex/0307022



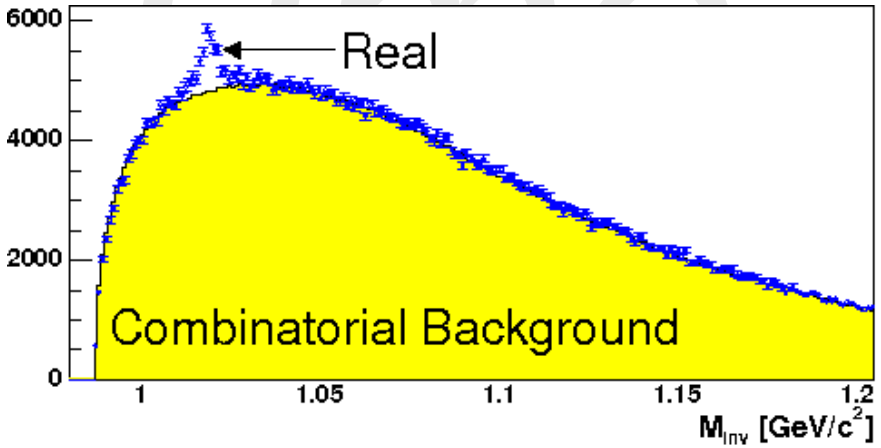
Physics Results

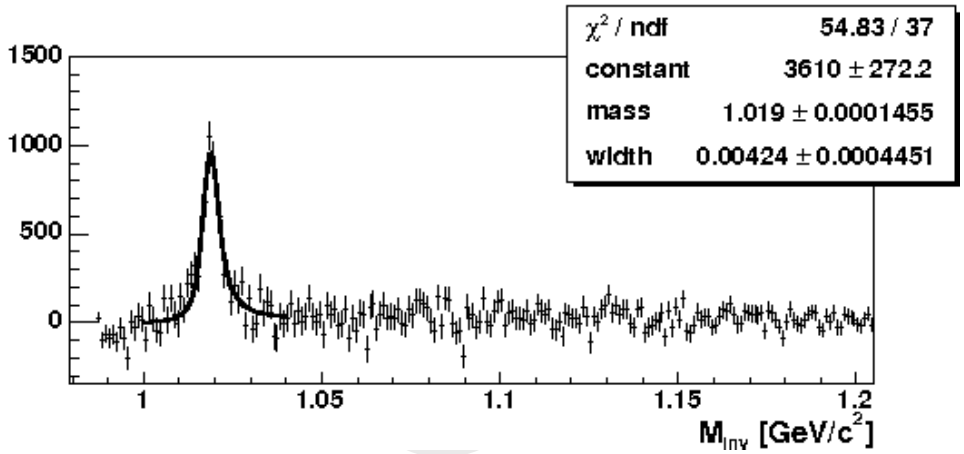




- Elliptic Flow of identified hadrons (π/K/p/d)
  - p_T < 2 GeV/c : Hydrodynamical picture
  - p_T > 2 GeV/c : quark/hadron coalescence ?

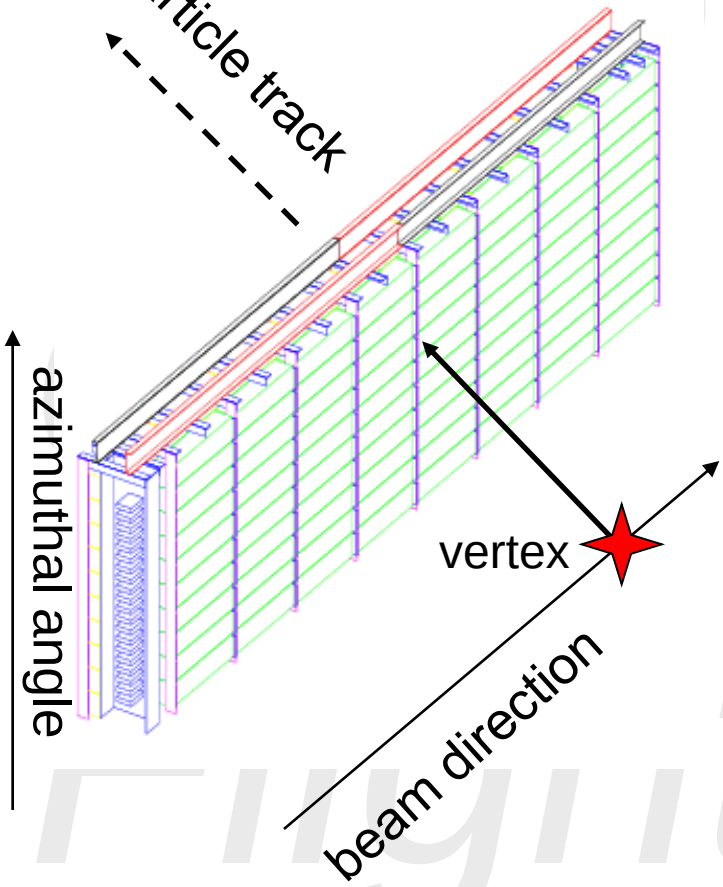
Physics Results





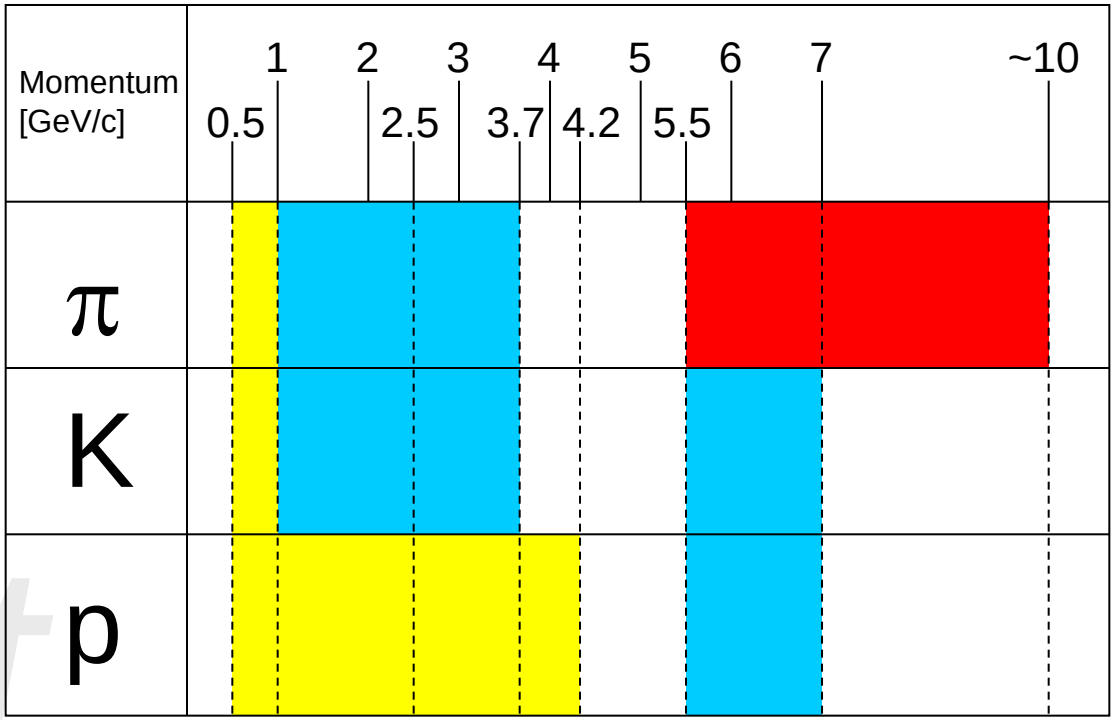
- ϕ meson measurement in K^+K^- decay.
- Invariant mass spectra
  - N = 5660 +/- 240
  - S/B = 1/8.5
- Transverse mass spectra
  - The Temperature is constant as a function of centrality.
- Elliptic Flow
  - Hydro. ? coalescence ?

PHENIX High-p_T upgrade



North-West Aerogel Counter
In PISA (by S. Takagi)

Aerogel : (n=1.010, threshold= 10 % of max $N_{p.e.}$)
TOF : 100 ps time resolution
RICH : CO_2, (n = 1.00041)



TOF
Aerogel (+ TOF or RICH)
RICH

PHENIX Focus
TOF group

Summary

- The PHENIX Time-of-Flight (TOF) is designed for Hadron measurement and operated for the PID.
  - π/K separation up to ~ 2 GeV/c.
  - K/p separation up to ~ 4 GeV/c.
  - Timing resolution is ~ 120 ps in Run2 Au + Au.
- TOF calibration is done in 4 steps and 6 parameters.
- TOF gives important physics measurements
  - Ex.
    - Single particle p_T spectra, R_{cp}.
    - Elliptic Flow of identified hadrons
    - ϕ meson measurement

Those who have contributed to the TOF detector.

And, of course, much more people are related to the past/coming successful construction/operation of it.

T.Kawagishi, M. Oka, M.Narisawa, Y.Nagata, T.Shoujou, S.Takagi, S.Kaminaga, M.Shimomura, M.Konno, S.Sakai, A.Danmura, H.Masui, S.Kato, S.Esumi, Y.Miake* (Univ. of Tsukuba, *DC-member)

Y.Kuroki, M.Ono, H.Tsuruoka, M.Aizawa, T.Hirano, K.Koseki, M. Suzuki, S.Urasawa, T.Shimada, H.Hayashi, R.Higuchi, Y.Miyamoto, Y.Yokota, D.Miura, T.Ishibashi, A.Kiyomichi, K.Enosawa, M.Nishimura, H.Sako, S.Nishimura, K.Kurita, K.Yagi (was in Univ. of Tsukuba (*1))

T.Chujo (BNL (*1)), S.Sato (JSPS/BNL (*1))

M.Inaba (Tsukuba College of Technology (*1))

D.Lim, J.Kang (Yonsei Univ.)

M.Chiu, C.Y.Chi (Columbia Univ. NEVIS)

M. Kaneta (KEK/Now @RBRC)

Lots of persons for the essential works in the past, and much more persons in the future.

Back up

From Susumu's nice presentation in
TOF Focus seminar last year

Infrastructure of TOF to Avoid a Fire.
~ Plastic Scintillators are Flammable. ~

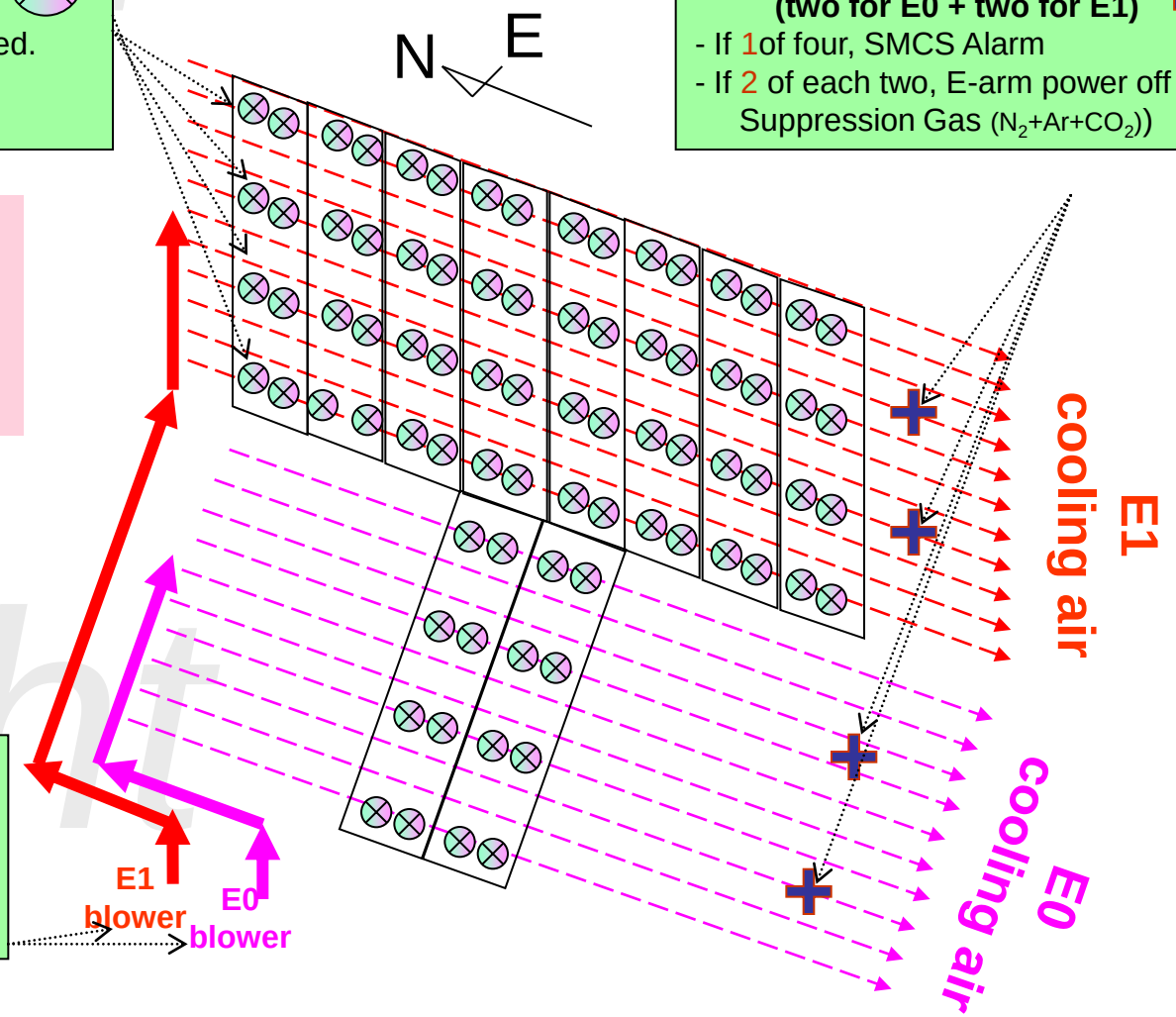
(III) 80 temperature sensors
(8 for each of 10 panels)
- If any T > 35 deg C, Adam monitor is Red.
- If any T > 35 deg C, SMCS Alarm .
  -Note: ~1W/PMT x 1920 PMTs

(II) 4 smoke sensors
(two for E0 + two for E1)
- If 1of four, SMCS Alarm
- If 2 of each two, E-arm power off + Suppression Gas (N_2+Ar+CO_2))

TOF-scintillators are in the **enclosed envelop** (for cooling air not to leak), although they are located very next to **~2000W** (~1W/PMT*1920PMTs)

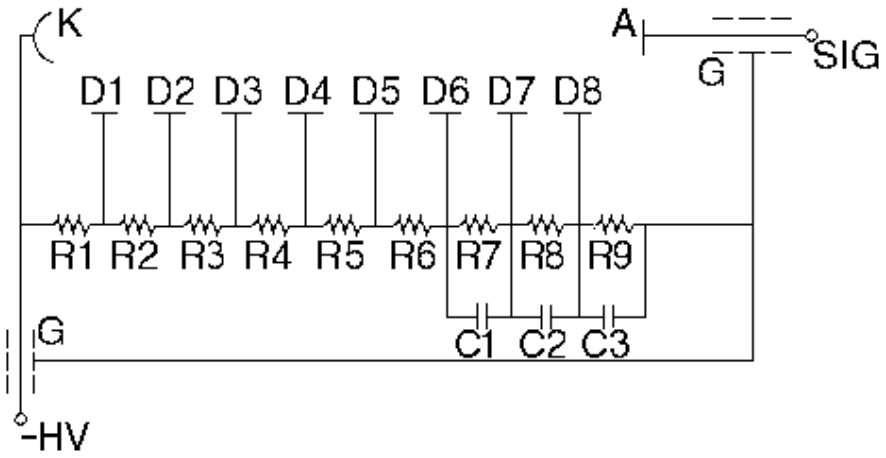
FYI: Blower Spec. Explosion proof (American National Electrical Code (NEC) Class 1, Group D) [Motor, Dayton 7F980; 0.75 HP, and Blower: Dayton 3C494; 13 and 11/16 inches diameter)

(II) 2 Cooling air blowers
(for E0 + for E1)
- If smoke, the air stops.
  And suppression Gas (N_2+Ar+CO_2) by its compressed pressure.



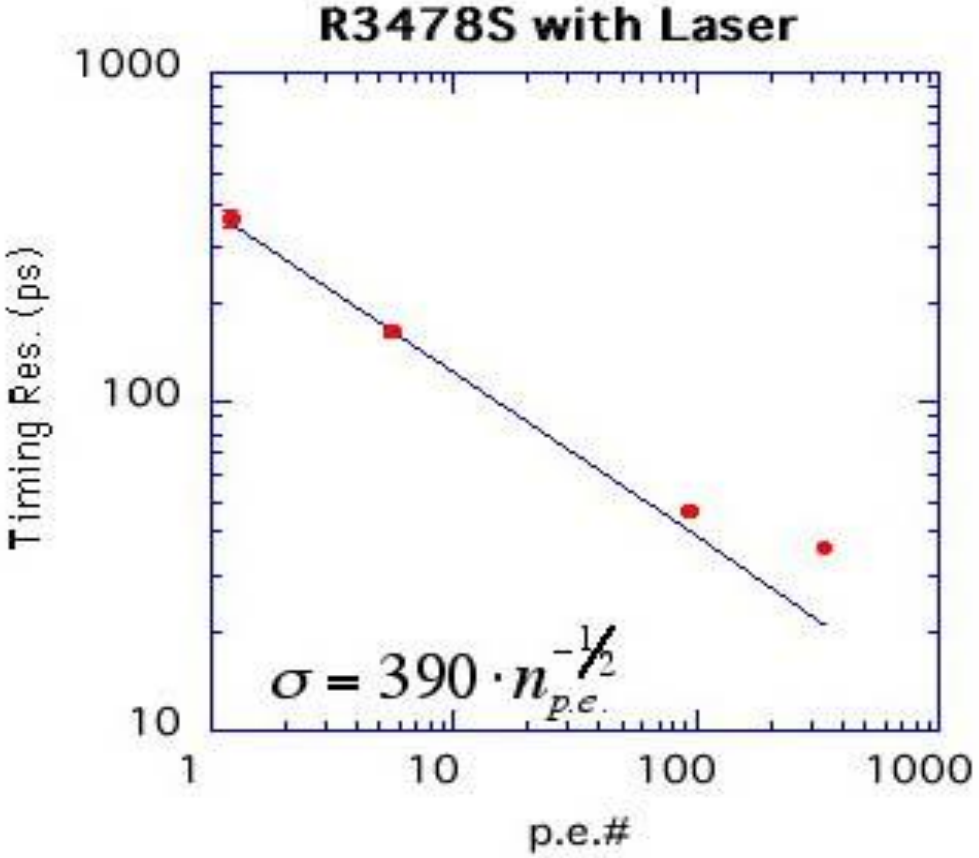
PMT & HV bleeder

Physical Parameter	Value
Spectral Response	300 to 650 nm
Wavelength of Max. Response	420 nm
Current Amplification	~ 3.9×10^6
Number of Dynodes	8 stages
Anode Pulse Rise Time	1.3 ns
Electron Transit Time	14 ns
Transit Time Spread (TTS) in FWHM	0.36 ns
High Voltage between Anode and Cathode	1800 DCV
Average Anode Current	0.1 mA
Ambient Temperature	- 80 to + 50 °C
Anode Dark Current (After 30 min. Storage in Darkness)	30 nA (typical)
Photo Cathode Material	Bialkali
Photo Cathode Min. Effective Area	15 mm in diameter



Schematic diagram of dynodes and bleeder for R3478s.
- Resisters are shown as *R* (*R1*=1.65 MΩ, 1/2 W; *R2*, *R4* ~ *R9* = 240 kΩ 1/4 W; *R3* = 360 kΩ).
- Capacitances are *C* (*C1* ~ *C3* = 0.01 μF, 200W).
-Dynodes are shown as *D1* ~ *D8*, the cathode are *K*, the anode are *A*.
-The high voltage is supplied at –*VH* (negative, -1800V) with ground (*G*) by PVC Jacketed #8411 coaxial cable of BELDEN.
-The signal output is shown *SIG* with ground (*G*) by RG58 coaxial cable of FUJIKURA.

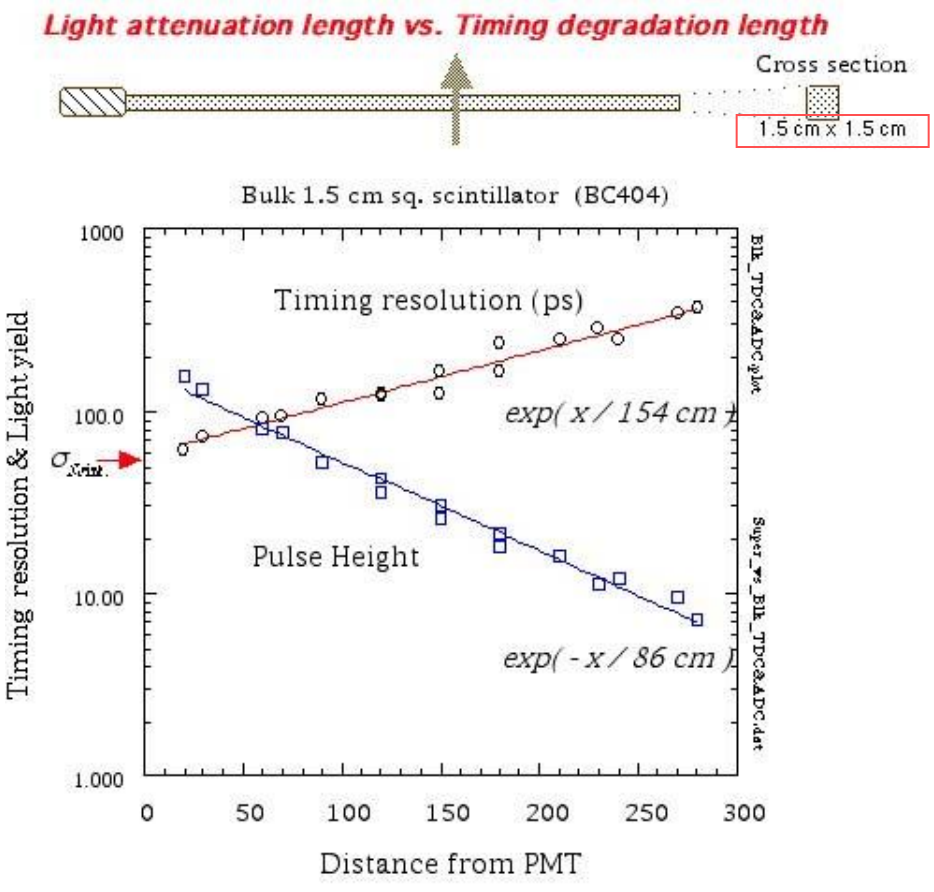
PMT intrinsic resolution



- Timing resolution decreases with larger p.e.#.
- **Resolution** < 100ps, for >10 p.e.
- Statistical behavior:
- At larger p.e.#, other mechanism.

$$\delta t \propto 1/\sqrt{n_{p.e.}}$$

Light attenuation vs. Timing degradation



- Intuitive explanation
  - Light yield ($\propto n_{p.e.}$) = $e^{x/\lambda}$.
  - Timing resolution $\propto n_{p.e.}^{-1/2} = e^{x/\lambda}$.

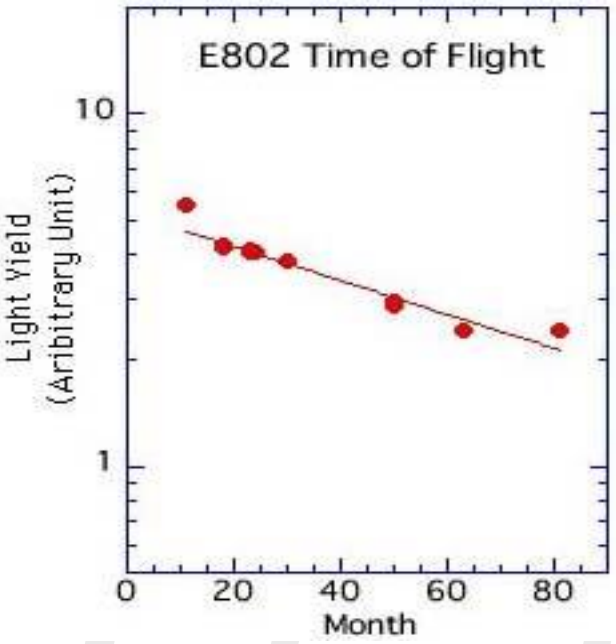
  → $\lambda_{timing} = 2 * \lambda_{yield}$

- Light yield decreases exponentially.
- Timing resolution degrades exponentially too.

$$\lambda_{timing} = 2 \cdot \lambda_{yield}$$

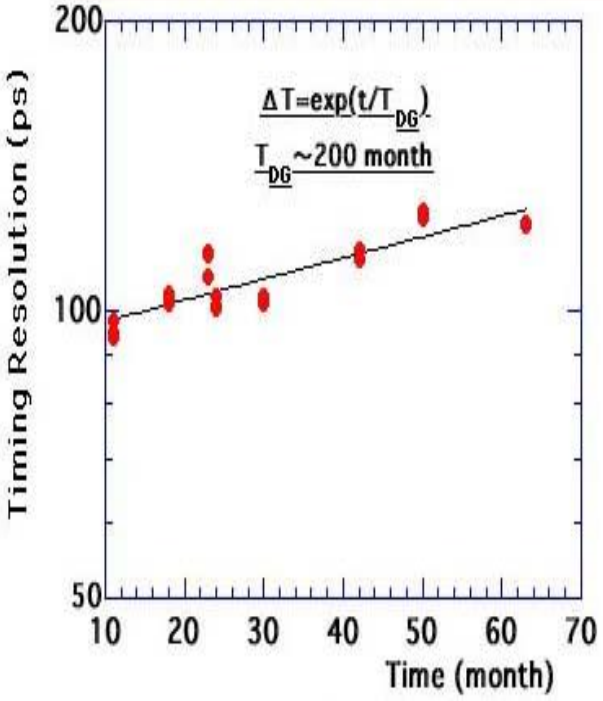
Aging effect

Pulse height



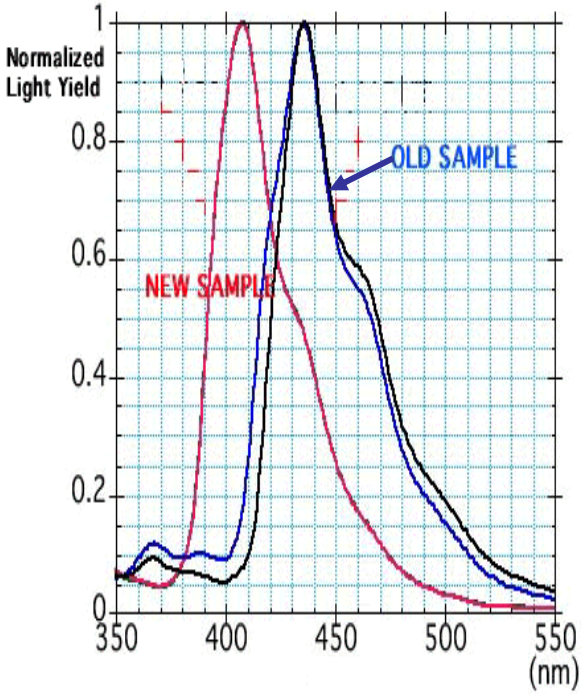
- Exponential decrease
- Life time of 8 years

Timing resolution



-Exponential degradation
-Lifetime of ~17 years

Optical property



-Change in emission spectrum
-More damage in the region closer to the surface
→ Oxidization ?

Consistent with statistical picture.